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STUDIES ON CONCENTRATION POLARIZATION FOR PURIFICATION OF SALINE WATER USING SPIRAL WOUND REVERSE OSMOSIS MODULE

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ABSTRACT

In this work the experimental studies were carried out to predict the performance of spiral wound reverse osmosis system. Experiments were conducted on laboratory scale spiral wound reverse osmosis module taking sodium chloride as a solute. The objective of this work is to study the effects of varying operating conditions such as feed pressure, feed concentration and feed flow rate on concentration polarization. The simplified form of solution diffusion model has been used to find the model transport parameters such as mass transfer coefficient and diffusivity. Observations indicated that as the feed pressure increases the mass transfer coefficient also increases and thus the concentration polarization decreases.

KEYWORDS: Concentration Polarization, Mass Transfer Coefficient, Diffusion Coefficient

INTRODUCTION

Reverse osmosis is most commonly used for the separation of dissolved salt and substances in solution. In this process the salty solution is pass through an appropriate porous membrane and withdrawing the membrane permeate at atmospheric pressure and ambient tempreture [1]. The rejected salt is deposited on high pressure side of the membrane, this phenomenon is known as concentration polarization. The concentration polarization and fouling of the membrane are two serious problems in reverse osmosis system. Both of these phenomenon are inhibit flux. The reduction of concentration polarization is important for the improvement of the performance membrane [2].

Various model have been developed for reverse osmosis system to describe the mechanism of solvent and solute transfer through reverse osmosis membrane. Typically, concentration polarization is modeled by using film theory but the film theory model has several limitations, such as lack of influence between permeate flow and boundary layer thickness, so more rigorous model have been proposed by kim and Hoek [3]. Recently a two scale model have been proposed by L.G. Palacin et al., [4] to overcome the limitation of film theory model and the result suggested that flux depends on several parameters, such as the membrane permeability or the temperature, but mainly on the salt concentration on the membrane surface.

Similarly S. Sundaramoorthy et al., [5] developed a mathematical model for predicting the performance of spiral wound reverse osmosis modules and proposed a new mass transfer correlation for Sherwood number by taking the effects of solvent flux, solute concentration and fluid velocity. Accurate prediction of concentration polarization phenomenon in reverse osmosis system is critical because it enhances trans-membrane osmotic pressure,surface fouling and scaling phenomenon so the objectives of this work is to find the effects of concentration polarization on reverse osmosis system. The effect of varying feed pressure, feed concentration and feed flow rate on concentration at the wall is given in this study. The effect of mass transfer coefficient along the feed channel with changing concentration polarization is also given.

EXPERIMENTATION

A commercial thin film composite polyamide RO membrane packed in a spiral wound module have been used for the experimental studies. Aqueous feed solution of sodium chloride of specific concentration was prepared by dissolving required quantity of NaCl in water. Taking around 300 L of feed solution in the feed tank, the RO unit was operated at a fixed inlet pressure and a fixed feed flow rate.For each run, before collecting the samples for analysis, the unit was operated for about 40 min to ensure the attainment of steady state. Steady state readings of inlet pressure, outlet pressure, permeate flow rate and retentate flow rate were recorded. Permeate and retentate concentrations were measured by collecting the samples of permeate and retentate solutions and analyzing them using titration agents $AgNO_3$ with potassium chromate K_2CrO_4 as an indicator

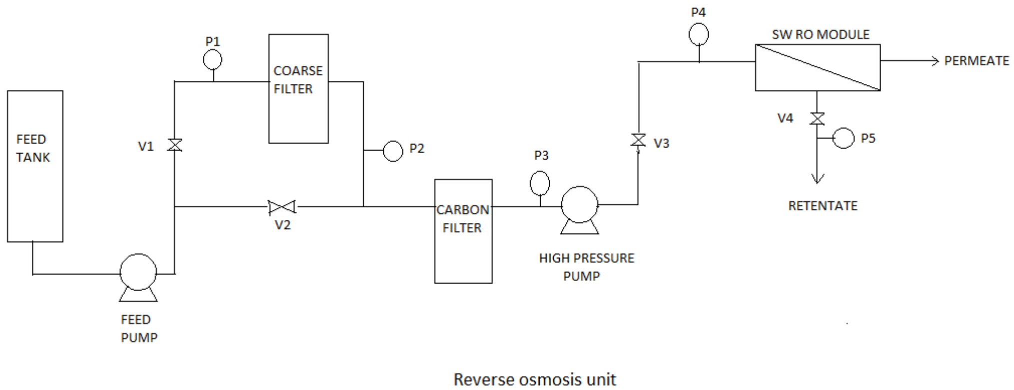

Figure 1: Schematic Diagram of Reverse Osmosis System

The feed temperature was recorded by reading the thermometer kept in the feed tank. For each experimental run, the steady state readings of permeate flow rate, retained flow rate, retained pressure, retained concentration, permeate concentration (C_p) and feed temperature(T) were recorded for a set of fixed values of feed concentration (C_b), feed flow rate (Q_f) and feed pressure (P).

MODELING

A complete model for the spiral wound reverse osmosis module is studied by combining the membrane transport equations that describe the solute and solvent flux through the membranes with the conservation and equation that describe the flow of material through the feed and permeate channels of the module.

The relationship between concentration polarization and permeate flux is

$$(C_w - C_p)/(C_b - C_p) = exp\,(V_w/k) \quad (1)$$

where C_w is concentration at the membrane surface or channel wall, C_b and C_p are the bulk and permeate solute concentrations respectively, V_w is the permeate water velocity at the channel wall and k is mass transfer coefficient. The permeate flux is described by

$$V_w = A\,(\Delta P - \Delta\,\pi) \quad (2)$$

where A is the water permeability of the membrane. The trans membrane osmotic pressure is given as

$$\Delta\,\pi = F_o(C_w - C_p) = F_oR_iC_w \quad (3)$$

where $R_i = (1 - C_p/C_w)$ is the intrinsic salt rejection of membrane and F_o is a coefficient that converts molar salt concentration to an osmotic pressure via an appropriate expression. van't Hoff's equation gives

$$F_o = 2RT \qquad \text{for NaCl} \tag{4}$$

Where R is the universal gas constant and T the absolute temperature. The mass transfer coefficient correlation available in the literature [4] is given by

$$k = 0.753 \left[\frac{K}{(2-K)}\right]^{0.5} \left(\frac{D}{h_b}\right) S_c^{(-1/6)} \left[\frac{P_e h_b}{L_{mix}}\right]^{0.5} \tag{5}$$

The value of concentration at wall of membrane can be calculated as

$$\frac{C_w}{C_b} = \left[1 - R_i + R_i \exp\left(-\frac{V_w}{k}\right)\right]^{-1} \tag{6}$$

which is called the concentration polarization modulus

RESULTS AND DISCUSSIONS

An analytical model for predicting the performance of spiral wound reverse osmosis modules have been studied. Experiments were conducted on laboratory scale spiral wound reverse osmosis module taking sodium chloride as a solute. During the experimentation feed concentration were varied from 100 ppm to 500 ppm and by taking feed pressure 5×10^5 Pa to 7×10^5 Pa. The readings of retentate concentration and permeate concentration were recorded. The hydrodynamic permeability was also calculated for varying operating conditions it varies from 1.03×10^{-11} m Pa^{-1} s^{-1} to 1.41×10^{-11} m $Pa^{-1}s^{-1}$.The figure 2 shows the permeate flow rate versus feed concentration. As shown in the figure 2 the feed concentration increases the permeate flow rate decreases linearly. This is because the osmotic pressure increases with increase in feed concentration. This reduces the driving force for the mass transferthus leading to lower volumetric flux.

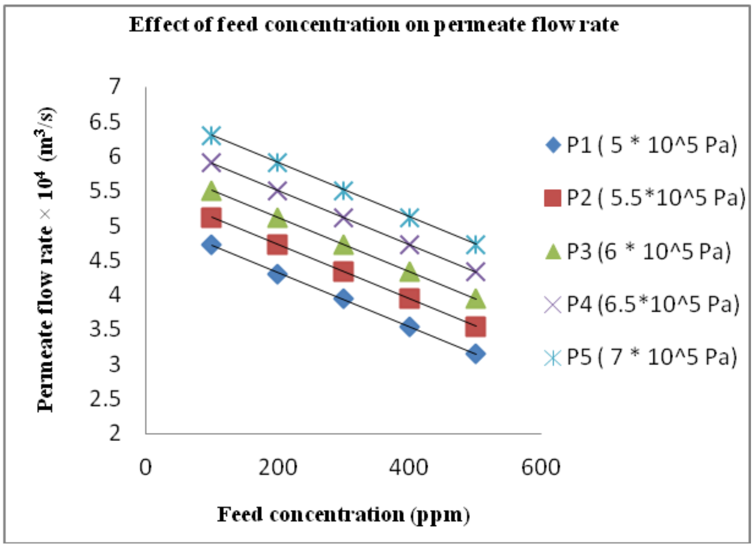

Figure 2: Effect of Varying Feed Concentration on Permeate Flow Rate

From the figure 3 it is observed that as the operating pressure increases the concentration at the wall decreases

significantly and it noticed that for the higher feed pressure the permeate concentration decreases and permeate flow rate increases due to increase in driving forces for mass transfer.

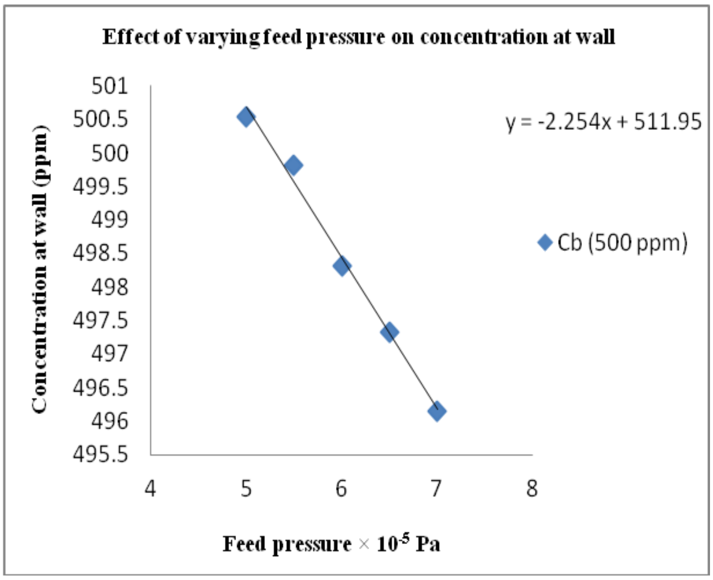

Figure 3: Effect of Increasing Pressure on Concentration at Wall

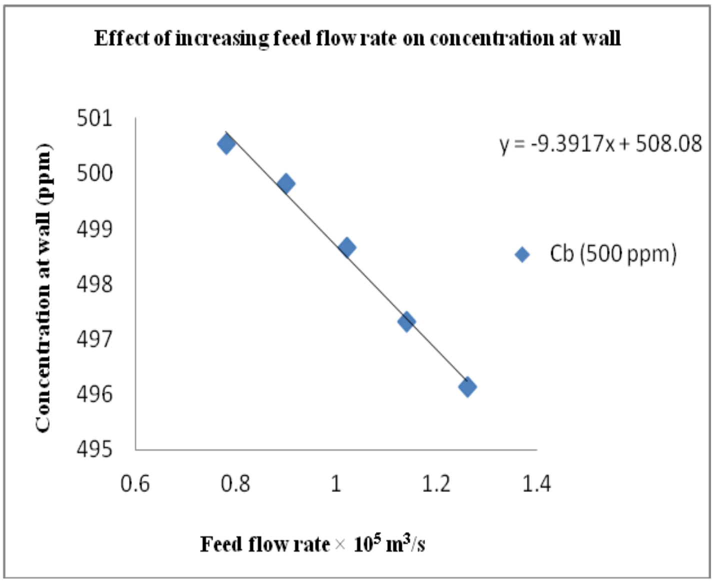

Figure 4: Effect of Increasing Feed Flow Rate on Concentration at Wall

From the figure 4 the value of concentration at wall falls with increasing feed flow rate. This is because as the velocity in the feed channel is increased the mass transfer coefficient also increases and thus the concentration polarization decreases. The feed flow rate increases due to increase in feed pressure. The mass transfer coefficient also increases thus the concentration polarization decreases. As shown in figure 5 the mass transfer coefficient increases with increasing feed pressure and figure 6 indicated that mass transfer coefficient is influenced by not only feed flow rate and feed pressure but also influenced by solvent flux and solute concentration.

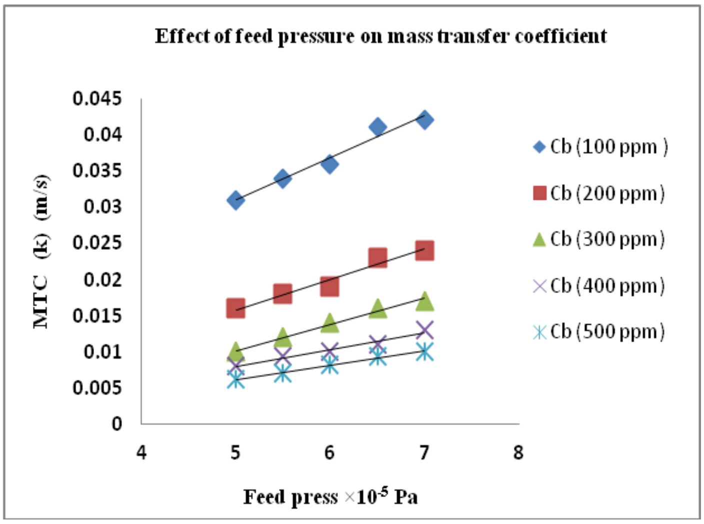

Figure 5 : Effect of Feed Pressure on Mass Transfer Coefficient

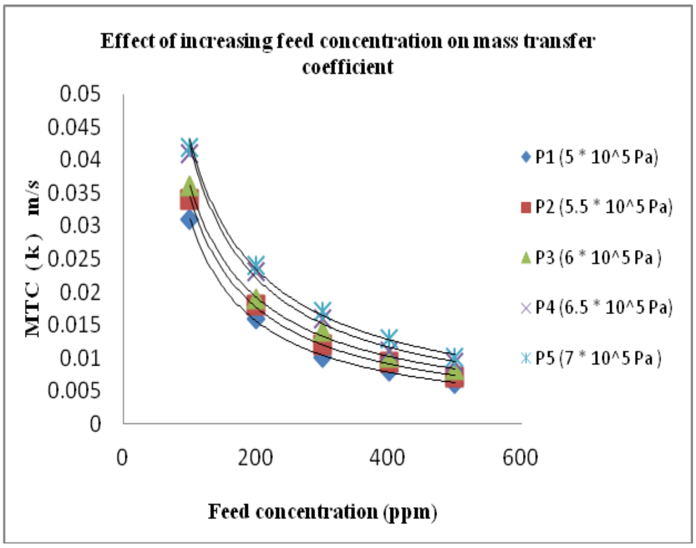

Figure 6: Effect of Feed Concentration on Mass Transfer Coefficient

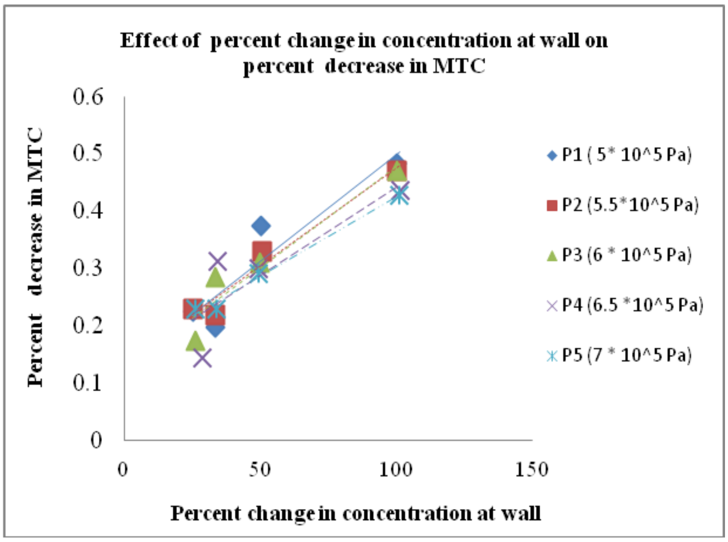

Figure 7: Effect of Percent Change in Concentration at Wall on Percent Change in MTC

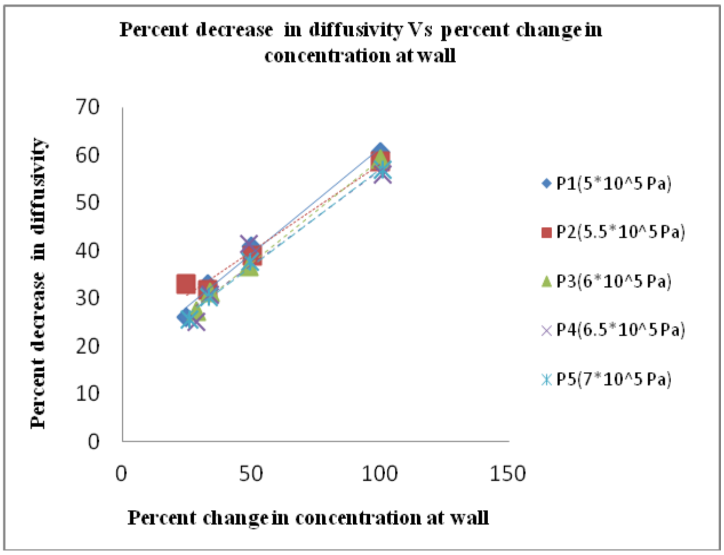

Figure 8: Effect of Percent Change in Concentration at Wall on Percent Decrease in Diffusion Coefficient

From the figure 7 and 8 as the concentration at the wall has increased it is found that rate of decrease of diffusion coefficient is more than mass transfer coefficient. The more sensitive value of diffusion coefficient indicates that the molecular diffusion has been affected at the wall due to concentration rise. This is the natural outcome of more resistance to diffusion at wall. Mass transfer coefficient is indicating the molecular transport because of diffusion and convection. The increase in wall concentration though has impact on diffusion it's impacts on mass transfer coefficient seem to be limited. This may be because of influencing role of transport through pore as compared to molecular diffusion. This transport in pore is more affected and confirm by pressure gradient and not by concentration gradient and hence the effect. It is demonstrated in this work.

CONCLUSIONS

A solution- diffusion model has been used to predict the behavior of spiral wound reverse osmosis module. The influence of concentration polarization on performance of reverse osmosis system have been studied in this work. The observations indicated that as feed pressure increases for same feed concentration, the concentration polarization decreases. As the feed concentration increases, the concentration polarization also increases. As the concentration at wall increased it is found that rate of decrease of diffusion coefficient is more than rate of decrease in mass transfer coefficient. This may be because of influencing role of transport through pore as compared to molecular diffusion.

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APPENDICES

Nomenclature

A - Pure water permeability, $m \cdot Pa^{-1}\ s^{-1}$

C - Retained concentration, mol/m^3

C_b - Solute concentration in the bulk, mol/m^3

C_p - Permeate concentration, mol/m^3

C_w - concentration at the wall of membrane, mol/m^3

V_w - Permeate flux, m/s

D - Diffusivity, m^2/s

Q_F - Feed flow rate, m^3/s

Q_p - Permeate flow rate, m^3/s

Q_R - Retained flow rate, m^3/s

$\Delta\pi$ - Osmotic pressure, Pa

ΔP - Operating pressure,Pa

R_i- Intrinsic salt rejection

R_o- Observed salt rejection

MTC - Mass transfer coefficient, m/s

P - Feed pressure, Pa

ρ-Density, kg/m^3